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Risk-Based Assessment of Appropriate Fuel Hydrocarbon Cleanup Strategies for China Lake Naval Air Weapons Station Navy Exchange Gas Station Site

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Submitted to the U.S. Navy, Southwest Division
Naval Facilities Engineering Command, San Diego, California

January 1998

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1. Program Overview

1.1. Introduction

In June 1994, the State Water Resource Control Board (SWRCB) contracted with the Lawrence Livermore National Laboratory/University of California (LLNL/UC) Leaking Underground Fuel Tank (LUFT) Team to study the cleanup of LUFTs in California. The study consisted of data collection and analysis from LUFT cases and a review of other studies on LUFT cleanups. Two final reports were submitted to the SWRCB in October and November 1995. These reports were entitled: *Recommendations To Improve the Cleanup Process for California's Leaking Underground Fuel Tanks (LUFTs)*, (Rice, et al., 1995a); and *California Leaking Underground Fuel Tank (LUFT) Historical Case Analysis* (Rice, et al., 1995b).

1.2. LUFT Demonstration Cleanup Program

1.2.1. Background

One of the important recommendations of this study was to identify a series of LUFT demonstration sites and to form a panel of experts made up of scientific professionals from universities, private industry, and Federal and State regulatory agencies. This panel would provide professional interpretations and recommendations regarding LUFT evaluations and closures at demonstration sites.

As a result of this recommendation, ten Department of Defense (DOD) sites were selected. Site selection was coordinated through the California Military Environmental Coordination Committee (CMECC) Water Process Action Team (PAT). Sites were selected to represent each branch of the military services with bases in California, as well as a number of Regional Water Quality Control Boards (RWQCB) and the diverse hydrogeologic settings in California where fuel hydrocarbon contaminant (FHC) cleanup problems occur. The China Lake Naval Weapons Center, within the Lahontan RWQCB, is one of the sites selected to participate in the DOD Petroleum Hydrocarbon Cleanup Demonstration (PHCD) Program. This program will be referred to as the DOD LUFT Demonstration Cleanup Program.

The other sites selected and their corresponding RWQCB region are:

- Army Presidio at San Francisco, San Francisco RWQCB.
- Barstow Marine Corps Logistic Center, Lahontan RWQCB.
- Camp Pendleton Marine Corps Base, San Diego RWQCB.
- Castle Air Force Base, Central Valley RWQCB.
- El Toro Marine Corps Air Station, Santa Ana RWQCB.
- George Air Force Base, Lahontan RWQCB.
- Port Hueneme Naval Construction Battalion Center, Los Angeles RWQCB.
- Travis Air Force Base, San Francisco RWQCB.
- Vandenberg Air Force Base, Central Coast RWQCB.

The Expert Committee (EC) selected to evaluate the selected demonstration sites are:

- Mr. David W. Rice, LLNL, Environmental Scientist; Project Director SWRCB LUFT Re-Evaluation Project; LLNL/UC LUFT Team member; DOD FHC Demonstration Program Coordinator.
- Dr. Walt McNab, LLNL, Hydrogeochemist, with expertise in the evaluation of passive bioremediation processes.
- Dr. William E. Kastenberg, UC, Berkeley, Professor and Chairman, Department of Nuclear Engineering; member of LLNL/UC LUFT Team, with expertise in environmental decision making and decision analysis processes.
- Dr. Lorne G. Everett, UC, Santa Barbara, Hydrogeologist; Director, Vadose Zone Research Laboratory, member of LLNL/UC LUFT Team, Chief Hydrologist with Geraghty & Miller, Inc., with expertise in vadose zone FHC transport mechanisms and passive bioremediation processes.
- Dr. Stephen Cullen, UC, Santa Barbara, Hydrogeologist; member of LLNL/UC LUFT Team with expertise in vadose zone FHC transport mechanisms and passive bioremediation processes.
- Dr. Paul Johnson, Arizona State University, Chemical Engineer; primary author of *American Society for Testing and Materials (ASTM) RBCA* guidance, with expertise in chemical fate and transport.
- Dr. Michael Kavanaugh, former Chairman, National Research Council Alternatives for Groundwater Cleanup Committee; Vice President, Malcolm Pirnie, Inc., with expertise in evaluation of groundwater remediation alternatives and environmental decision making processes.
- Mr. Matthew Small, U.S. EPA Region IX, Hydrogeologist; Co-Chairman of U.S. EPA Remediation by Natural Attenuation Committee, with expertise in risk-based corrective action and passive bioremediation.

1.2.2. Risk-Based Corrective Action

The LLNL/UC recommendations report concluded that risk-based corrective action (RBCA) provides a framework to link cleanup decisions to risk. The DOD LUFT Demonstration Cleanup Program provides a series of sites where the application of a risk-based cleanup approach can be demonstrated.

For a risk to exist, there must be a source of a hazard, a receptor, and a pathway that connects the two. All three factors must be addressed to determine whether a LUFT release poses a risk to human health, safety, or the environment. If the source, pathway, or receptor are at all times absent, there is, by definition, no risk. The distinction between sources, pathways, and receptors may be context-dependent in many cases and therefore must be carefully defined. For purposes of the present assessment, definitions of these terms are developed by working backward from the receptor to the source:

Receptor: Human or ecological risk receptors which may potentially be subject to damage by exposure to hydrocarbons via ingestion, inhalation, or absorption. This definition also specifically includes water supply wells because it must be assumed that humans will be ingesting the water from these wells.

Pathways: Physical migration routes of contaminants from sources to risk receptors. This definition specifically includes the groundwater environment downgradient of the source that provides a medium through which dissolved contaminants may migrate to water-supply wells, as well as to surface water bodies which may serve as ecological risk pathways. The definition also includes the vadose zone in the immediate vicinity of the source, where vapor migration routes to nearby human receptors may exist.

Sources: Points of entry of contaminants into possible exposure pathways. In the case of hydrocarbon releases associated with LUFT sites, separate-phase hydrocarbon product which can either dissolve into the aqueous phase or volatilize into the gaseous phase constitutes a source. Primary sources will include underground tanks and associated piping; secondary sources will include any separate-phase hydrocarbon or free-product material residing within sediment pores.

From a mathematical viewpoint, sources and receptors represent boundary conditions for the problem of interest (influx and outflux, respectively); pathways represent the problem domain. Thus, in some special situations, the dissolved plume in groundwater may represent a source, such as in the case of Henry's law partitioning of contaminants from the aqueous phase into the gaseous phase. On the other hand, hydrocarbons which have adsorbed onto sediment surfaces from the aqueous phase cannot be regarded as potential sources in most situations according to this definition, but rather exist as part of the pathway.

Risk characterization is defined as an information synthesis and summary about a potentially hazardous situation that addresses the needs and interests of decision makers and of interested and affected parties. Risk characterization is a prelude to cleanup decision making and depends on an iterative, analytic, and deliberative process. This process attempts to gather all relevant data so the decision makers may then choose the best risk-management approach.

1.2.3. The Appropriate Use of Passive Bioremediation

The Recommendations Report also concluded that with rare exceptions, petroleum fuel releases will naturally degrade (passively bioremediate) in California's subsurface environments. The DOD LUFT Demonstration Cleanup Program provides sites where the appropriate use of passive bioremediation can be evaluated.

Passive bioremediation can control groundwater contamination in two distinct ways:

- First, passive bioremediation substantially lowers the risk posed to downgradient risk receptors through plume stabilization¹.
- Second, passive bioremediation actively destroys fuel hydrocarbon mass in the subsurface, leading to remediation of contamination over time (e.g., eventual contaminant concentration decline and depletion of the dissolved hydrocarbon plume). From a risk-management viewpoint, the stabilization of the dissolved plume and associated reduction in exposure potential is the most important contribution of passive bioremediation.

The role of passive bioremediation in controlling the behavior of dissolved hydrocarbon plumes may be evaluated through both primary and secondary field evidence.

- Primary evidence includes quantitative evaluation of plume stability or plume shrinkage based upon trends in historical groundwater contaminant concentration data.
- Secondary evidence includes indirect indicators of passive bioremediation, such as variations in key geochemical parameters (dissolved oxygen, nitrate, sulfate, iron,

¹ Even in the presence of a continuous constant source of fuel hydrocarbons (e.g., dissolution of residual free-product components trapped in the soil matrix), a groundwater plume subject to passive bioremediation will reach a steady-state condition in which plume length becomes stable. This will occur when the rate of hydrocarbon influx from dissolution of the residual free product source is balanced by the rate of mass loss via passive bioremediation, integrated across the entire spatial extent of the plume.

manganese, methane, alkalinity/carbon dioxide, Eh, pH) between measurements in fuel hydrocarbon-impacted areas and background.

Although primary evidence of plume stability or decline generally provides the strongest arguments to support natural attenuation at a given site, such evidence may not be available because adequate historical groundwater monitoring may not exist. In these cases, short-term monitoring data providing secondary lines of evidence, in conjunction with modeling where appropriate, may support a hypothesis for the occurrence of passive bioremediation. Consequently, means for assessing the role of passive bioremediation in controlling risk by secondary lines of evidence should be fully explored at such sites.

Appropriate use of passive bioremediation as a remedial alternative requires the same care and professional judgment as the use of any other remedial alternative. This includes site characterization, assessment of potential risks, comparison with other remedial alternatives, evaluation of cost effectiveness, and the potential for bioremediation to reach remedial goals. Monitoring process and contingency planning must be considered as well.

Passive bioremediation may be implemented at a given petroleum release site either as a stand-alone remedial action or in combination with other remedial actions. The need for active source removal must also be addressed on a site-by-site basis. Source removal includes removing leaking tanks and associated pipelines, and any remaining free product and petroleum fuel saturated soil, as much as economically and technically feasible. When properly used, passive bioremediation can help manage risk and achieve remedial goals.

1.2.4. The DOD LUFT Demonstration Cleanup Program Steps

The demonstration program process can be summarized in the following nine steps:

- Step 1: Site scoping meeting with site staff, regulators, and EC staff representatives. Develop and discuss site conceptual model. Identify and discuss pathways and receptors of concern.
- Step 2: RBCA training for DOD Petroleum Hydrocarbon Cleanup Demonstration Program (PHCDP) participants.
- Step 3: Site staff and contractors prepare the data package. EC staff reviews available data and identifies data gaps needed to apply a risk-based cleanup approach.
- Step 4: EC visits site and receives briefing, on site characterization, conceptual model, and pathways and receptors of concern. Site tour is included in this briefing. Following EC's visit, a site characterization report is prepared by the EC containing recommendations for further data collection, if needed (See Appendix A).
- Step 5: EC staff applies a risk-based cleanup approach to the Site using best available data.
- Step 6: EC staff evaluates the natural attenuation potential for the Site using best available data. An estimate of the time to clean up and the uncertainty associated with this estimate will be made. Sampling and monitoring procedures to support intrinsic bioremediation for the site will be identified.
- Step 7: Based on the concept of applied source, pathways, and receptors as to potential hazards, site specific findings regarding natural attenuation potential, and discussion with regulators, the EC shall provide its recommendations for an appropriate risk-management strategy at the site and the set of actions needed to achieve site closure. The EC will present its recommendations at an appropriate forum.
- Step 8: The EC will provide a DOD LUFT Demonstration Cleanup Program overall evaluation comparing the effectiveness of risk-based cleanup at each site in the program. An estimation of the cost savings using risk-based cleanup protocols will

be compared to baseline approaches. An estimation of the value of the remediated water will be made.

- Step 9: The EC Staff will produce a DOD Risk Execution Strategy for Clean-Up of the Environment (RESCUE) implementation guide and accompanying procedures manual (Phase I, Petroleum) that can be used in California and in other states by military bases.

2. Site Overview

2.1. Background and Site History

The Naval Air Weapons Station (NAWS), in China Lake California is located in the upper Mojave Desert of California, approximately 150 miles northeast of Los Angeles. The Navy Exchange (NEX) Gas Station Site (Site) is located in the northeast corner of North Richmond Road and King Street, an area that is within the southern portion of the China Lake Complex at the NAWS China Lake Main Site. The NEX Gas Station has been in operation at the Site since 1967. Three 12,000 gallon steel single shell underground storage tanks (USTs) for product storage were originally installed at the north end of the station building, and one steel waste oil UST was installed on the east side of the station building, all in 1967. In September 1991, during excavation and removal of the most westerly tank, strong odors and soil staining were noted. All tanks were suspected of leaking between 1967 and 1992 (Weston, 1992a). In that year, all tanks were repaired and passed tightness testing (Weston, 1992a).

In 1993, during replacement of the original tanks and piping, an uncapped segment of product piping was discovered extending past the third pump island on the Site. This uncapped segment was presumably intended as a product pipe connection to a proposed fourth dispenser island that was not constructed (Montgomery Watson, 1997). This uncapped product pipeline is suspected to be the primary source of fuel hydrocarbons (FHCs) found in the soil and groundwater at the Site. The duration of the discharge from this open pipeline is uncertain, but presumably, discharge of FHCs occurred continuously between 1967 and 1993.

The waste oil tank was removed in September 1990, and was found to be leaking. Affected soils were removed along with the tank (Weston, 1992a).

The Site has undergone numerous soil and groundwater investigations, beginning in 1989. Soil and groundwater have been sampled for FHCs by several consultants (Jaykim Engineers, 1990; Weston, 1992a; Smith-Gutcher, 1993 and 1995; Radian, 1996 and 1997; PRC, 1994 and 1997) and soil vapor has recently been tested (Montgomery Watson, 1997). Weston (1992b) proposed remedial actions at the Site including a soil vapor extraction system for soil remediation, and a pump and treat system for groundwater remediation. The latter system has never been installed. Currently, there are 12 monitor wells installed in the water table aquifer. An additional 16 hydropunch samples of groundwater were collected by Weston, in 1991 (Weston, 1992a), and a recent investigation using the US Navy Site Characterization and Analysis Penetrometer System (SCAPS) provided an additional 13 groundwater samples (PRC, 1997). Montgomery Watson (Montgomery Watson, 1997) also completed a screening level human health risk assessment, for inhalation exposure, based on soil vapor data. AGS, Inc. (AGS, 1997) completed a baseline risk assessment for both human health and ecological risks, based on existing data, and assuming a no further action remedial response at the Site.

2.2. Site Characterization

2.2.1. Geology and Hydrogeology

The China Lake Naval Air Weapons Complex is situated in the southwestern corner of the Basin and Range Physiographic Province within the Indian Wells Valley. This valley is a down-dropped graben, filled with alluvial deposits of variable depths. Locally the Site is underlain by interbedded, poorly graded sand, clay, silty sand, and silty clay (Weston, 1992a).

Groundwater depths vary considerably from one part of the NAWS to another. In 1989 to 1990, depth to the first water bearing unit in the vicinity of the Site was approximately 30 feet below ground surface (bgs). Thickness of this water bearing unit averaged 20 feet based on observations from six monitor wells (Weston, 1992a). Below this water table aquifer, a confining clay layer of unknown thickness exists which acts as an aquitard between the first water bearing unit (water table aquifer), and the lower aquifer unit. Well logs from a number of water-supply wells indicate that this confining clay layer may be several hundred feet thick, and that the top of the productive lower aquifer unit is approximately 550 feet bgs.

The groundwater flow in the water table aquifer trends towards the southeast, a direction that has been confirmed by several groundwater level monitor events (Weston, 1992a; Radian, 1996). However, the distribution of contaminants in the groundwater suggests that groundwater flowing beneath the Site has also migrated in a southwestern direction. The timing and duration of this flow direction since the time of the FHC release is unknown. The hydraulic gradient has been reported to range from 0.001 ft/ft (Radian, 1996) up to 0.04 ft/ft (Weston, 1992a). Weston (1992a) suggests an average gradient of 0.009 ft/ft which seems reasonable based on a review of the groundwater elevation data. Weston reports an average saturated porosity of 0.27, which is consistent with the stratigraphy of the saturated zone. Weston (Weston, 1992a) also reported the results of two pump tests using three of the monitor wells in the immediate vicinity of the Site. The reported transmissivity values at these locations ranged from 0.13 to 6.1 ft²/min. The thickness of the aquifer near these wells was approximately eight feet based on geologic cross sections prepared by Weston, which results in hydraulic conductivities ranged from 23.4 ft/day up to 1,100 ft/day. Thus, average groundwater velocities could range from 0.8 ft/day to 37 ft/day assuming the above average porosity. Given that the FHCs may have reached the groundwater in the early 1970s, and that the apparent plume length (based on 1 µg/L, benzene) is less than 1,600 feet from the primary source areas, the lower groundwater flow rates are more probable.

However, based on recent test results on the fraction of organic carbon in soils at the Site (PRC, 1997), some retardation of the BETX compounds is likely. Based on an average soil organic carbon of 0.07 percent, and using appropriate correlations (Schwarzenbach et al., 1993), it can be shown that the retardation factors for benzene, toluene, and ethyl benzene are 1.03, 1.58, and 2.67, respectively. Thus, in the absence of biodegradation, benzene can travel about as fast as the groundwater, but the rate of toluene and ethylbenzene migration will decrease relative to the rate of benzene migration due to adsorption on soil. This sequence of migration for these hydrocarbons is consistent with Site groundwater monitoring results.

2.2.2. Distribution of Contaminants in Soil and Groundwater

The organic chemical constituents of concern identified in the soil and groundwater at the Site consist of volatile aromatic hydrocarbons, total petroleum hydrocarbons as gasoline, and methyl *tertiary*-butyl ether (MTBE), typical of FHC releases from USTs. MTBE is a gasoline additive blended with gasoline sold in California after approximately 1986 to increase octane rating, and the oxygen content of gasoline. No other chemical contaminants have been reported. It is likely that other gasoline constituents are present in the soil and groundwater, because the TPH_g measurement encompasses a limited range of alkanes present in gasoline. However, the

aromatic hydrocarbons and MTBE represent the constituents of FHCs posing the predominant potential risks to human health and the environment because of their toxicity and relative mobility in the saturated zone beneath this Site.

The extent of fuel hydrocarbon (FHC) contamination in the soils is well defined based on the soil boring investigation completed by Weston (Weston, 1992a) and supplemented by the recent SCAPS based testing program which provided an additional 14 soil samples from the Site and from areas downgradient of the Site. Results for BETX and TPH_g were below detection limits in all soil samples collected.

The horizontal extent of FHC contamination in the groundwater is now well defined due in part to completion of recent Site investigation studies, which were recommended in the Site Assessment letter prepared by the Expert Committee of the DOD Petroleum Hydrocarbon Cleanup Demonstration Program (See Appendix A). As noted in the Site Assessment letter, the upgradient and easterly limits of the apparent BETX and TPH_g plumes were reasonably well defined. The location of the western edge of the BETX plume, based on the 1 µg/L groundwater concentration, is also now defined based on the SCAPS testing program (PRC, 1997). BETX levels in monitor well NGE-7 are below detection limits based on the recent round of groundwater monitoring in May 1997 (Radian, 1997). The hydropunch result from HP-12, taken in 1991 was non-detect, and this location appears down or cross gradient from NGE-7. BETX levels in NGE-10 are also below detection limits, and three SCAPS samples from W09, W08, and W06 all show BETX and TPH_g at levels below detection limits.

The most recent round of groundwater sampling, in April 1997 has also confirmed the presence of MTBE in the groundwater up to a maximum concentration of 1,100 µg/L in monitor well NGE-5. In the eastern edge of the BETX plume, MTBE appears to extend as far as well NGE-9, about 1150 feet from source area. MTBE was detected in NGE-9 at a level of 17 µg/L, increasing from <0.5 µg/L as reported in the October 1996 monitoring program. Interestingly, BETX concentration in NGE-9 and in W14 were ND in the April 1997 samples. Thus, it appears that MTBE now extends beyond the edge of BETX plume in this area. In the western edge of the plume, MTBE is non-detect in NGE-10, but is present in upgradient monitor wells. Thus, in this portion of the BETX plume, MTBE remains within the probable boundaries of the apparent BETX plume.

Finally, the leading edge of the BETX plume has been confirmed. BETX and TPH_g levels in SCAPS samples W12, W14, and W13, which are located south of the primary source area, are all below detection limits. In addition to the presence of dissolved FHCs, there appears to be a significant quantity of residual gasoline product in the groundwater south of the Site. The source of this residual product appears to have been gasoline releases from the uncapped pipe. In contrast to probable slow leaks from the tanks, or tank pipe connections, the uncapped pipe probably caused a continual release of FHCs for 23 years. Releases of FHCs from this source are likely responsible for the BETX and TPH_g levels reported in samples from NGE-4, NGE-5, and

NGE-11. This source is also probably responsible for the high BETX and TPH_g values observed in the recent (1997) SCAPS groundwater samples from W10, W03, W04, W11, and W01. Total BETX values from these five samples were 7,900, 12,400, 640, 5,300, and 11.4 µg/L respectively. MTBE appears to be absent from the groundwater at the apparent western edge of this plume, as shown by ND values for MTBE in groundwater samples from NGE-10 and W01.

Although these primary sources have been removed, the significant quantities of gasoline released from the uncapped pipeline appear to have caused a secondary source of groundwater contamination that continues to impact groundwater quality. According to the recent AGS report (AGS, 1997), the iso-contour lines representing a concentration for TPH_g of 10,000 µg/L extends almost 1,100 feet from the original point of release. There appears to be a continuous zone of the aquifer containing more than 10,000 µg/L TPH_g, extending from monitor well NGE-4 to W11. Although no free product has been observed in any of the groundwater samples

collected since 1991, the concentrations of TPH_g exceed 1 percent of the nominal solubility of gasoline in water (approximately 1,800 µg/L based on 180 µg/L solubility), indicating the probable presence of residual gasoline in the vicinity of the monitor wells. Although the soil gas data do not indicate the presence of significant residual gasoline, groundwater samples from monitor wells within the 10,000 µg/L isocontour line continue to show BETX and TPH_g values well above the 1 percent solubility rule, based on the May 1997, sampling data.

The EC does not agree with the recent conclusion by AGS (AGS, 1997) that no free or residual product is present at the Site because the concentrations of BETX do not exceed 10 percent of the pure compound solubility. The 10 percent rule of thumb indicating the presence of a NAPL is not supported by most experts in the field who have studied the fate and transport of NAPLs in the subsurface (see for example, U.S. EPA, 1993; Pankow and Cherry, 1996). Furthermore, dissolved phase concentrations must be compared to the effective solubility for the specific chemical compound in mixture. For example, in the case of gasoline containing 2 percent benzene, the effective solubility is approximately 350 µg/L, not 1,750 µg/L. Thus, concentrations of benzene above 3,500 µg/L or 1 percent of the effective solubility would indicate the probable presence of residual product.

3. Site Conceptual Model

A well defined conceptual model of a site contains sufficient information to: (a) identify sources of the contamination, (b) determine the nature and extent of the contamination, (c) identify the dominant fate and transport characteristics of the site, (d) specify potential exposure pathways, and (e) identify potential receptors that may be impacted by the contamination. A conceptual model for the NEX Site has not yet been fully developed, in part because of uncertainties related to the sources of suspected or potential releases, and because of anomalies regarding the distribution of contaminants in the groundwater. A summary of key components of the Site conceptual model is provided in this section.

3.1. Sources

3.1.1. Primary Sources

The primary sources of FHC contamination at the Site have been identified. FHC releases from three former USTs previously located a few yards from the Station Building and associated product piping likely caused contamination of the groundwater beneath these tanks. A second release point, an uncapped product pipeline, was found a short distance from the end of the most westerly of the three USTs. This pipe is the likely source of the majority of FHCs found in the soil and groundwater at and downgradient of the Site. These primary sources have been removed or eliminated including a substantial amount of contaminated soil in the immediate vicinity of the former USTs (Weston, 1992a). The EC has not been provided any evidence that the newly installed tanks have passed tank leak detection testing, but it is presumed that the integrity of the new tanks has been established, and that these tanks will meet EPA's 1998 mandated UST management requirements.

3.1.2. Secondary Sources

Groundwater sampling events in 1990 to 1991 indicated the presence of floating product in well NGE-4. The TPH_g level in that sampling event was 66 mg/L. Concentrations of TPH_g and BETX in NGE-5 and NGE-11 from the 1991 sampling event also suggested the presence of free or residual product. The presence of residual or floating product would be anticipated based on the release scenario from the primary sources.

In two subsequent groundwater sampling events (June 1996 and October 1996), no floating product was reported in any of the ten monitor wells sampled. The lack of apparent floating product in any of the 12 groundwater monitor wells was confirmed in the May 1997 sampling event (Radian, 1997). However, during the October 1996 sampling event, concentrations of BETX in well NGE-11 were well above the 1 percent solubility limit suggesting the presence of non-aqueous phase liquids (NAPLs) (U.S. EPA, 1993; Pankow and Cherry, 1996). (For example, the concentration of toluene was approximately 7 percent of aqueous solubility at 25 degrees Celsius). The concentration of TPH_g in both wells NGE-5 and NGE-11 exceeded approximately 20 percent of the aqueous solubility for gasoline (180 to 200 µg/L). Concentrations of BETX and TPH_g are still high in these two monitor wells (Total BETX of 20,730 and 45,700 µg/L and; TPH_g of 39,000 and 57,000 µg/L in NGE-5 and NGE-11, respectively), even in the most recent sampling event (Radian, 1997). This suggests that a secondary source of FHCs near these monitor wells has not yet dissipated and still remains a continuing source of FHC contamination to the groundwater.

The magnitude of this secondary source is not known. However, the recent soil gas testing (Montgomery Watson, 1997) did not detect any BETX in soil gas extended to 10 feet bgs in the vicinity of these wells. Furthermore, TPH_g levels have decreased in all monitor wells between the October 1996 and May 1997 sampling events. This evidence suggests that the magnitude of the secondary source of FHCs in the vicinity of wells NGE-5 and NGE-11 may be decreasing. Decreases in MTBE between the October 1996 and May 1997 sampling events support this observation. The cause of this decrease is uncertain, but since it is known that MTBE does not degrade in the presence of BETX, volatilization or anaerobic degradation may be the main causes of FHC reduction observed in these monitor wells. The rate of this decrease is unknown.

3.2. Exposure Pathways

Human health or ecological risks arise when a complete exposure pathway exists connecting a point of chemical release to a potential receptor. At this Site, potential exposure pathways include the following:

- Inhalation of FHC vapors migrating through the vadose zone.
- Inhalation of FHCs emitting from water during use (e.g., showering).
- Absorption of FHCs through the skin during showering.
- Ingestion of FHC constituents present in the water table aquifer.
- Ingestion of FHC constituents possibly present in the deeper aquifer.

Migration of FHCs to the deeper aquifer is unlikely given the thickness of the confining clay layer beneath the water table and thus, this latter exposure pathway is likely incomplete.

Other exposure pathways that could be considered include incidental ingestion of contaminated soil, dermal contact with contaminated soil, and inhalation of wind-blown particulates. None of these exposure pathways are pertinent to this Site because the only medium of concern at this time is groundwater. Recent soil sampling results confirm that contaminated soil is not an issue at this Site (PRC, 1997).

3.3. Receptors

According to information prepared for the EC (Radian, 1996), there are no water-supply wells within 1.5 miles of the NEX Site. The shallow groundwater is not likely to be used as a drinking water source in the future because of poor quality (TDS greater than 1,200 mg/L) and because the NAWS currently has an extensive water-supply system, relying on water extracted

from the deeper regional aquifer. The water from the shallow aquifer could potentially be used for non-potable uses, however. Thus, risks to human health from ingestion of water is not an immediate issue at this Site. If the water were used for irrigation, volatilization of the BETX compounds and MTBE would occur, and human exposure is conceivable.

Migration of vapors from the subsurface could reach human receptors who live on the base in areas overlying or near the BETX and MTBE plumes. One area of concern is the nearby Murray High School, located about 150 feet west of the BETX plume. Although the direction of groundwater appears to be south southeast, away from the school, groundwater analyses from well NGE-11, which is located southwest of the primary source area, show the highest levels of BETX and TPH_g during all four groundwater sampling events. The highest levels of MTBE were found during the two most recent sampling events. Volatilization of BETX in the subsurface and migration of the organic vapors to the ground surface is plausible, although the recent soil gas test program as discussed earlier, does not support this hypothesis.

In summary, potential receptors include current or future onsite workers, students at Murray High School who are located within the area extent of the BETX plume, and residents that might be exposed to FHCs released from shallow aquifer groundwater during irrigation used for irrigation. In addition, potential ecological receptors should be considered if irrigation use of the shallow water is planned.

China Lake Naval Weapons Center recently contracted for the preparation of a baseline risk assessment, consistent with EPA guidance on human health and ecological risk assessment. The report (AGS, 1997) summarizes estimates of potential human health and ecological risks under a no-further action scenario. The report considered the following onsite and offsite receptors:

Onsite:

- Outdoor construction worker.
- Outdoor commercial/industrial worker.
- Indoor construction worker.
- Indoor commercial/industrial worker.

Offsite:

- Child receptor.
- Indoor commercial/industrial worker in three buildings.

The report concluded that risks to human health and the environment were insignificant under a no-further action scenario.

4. Risk Analyses and Management

4.1. Fate and Transport of Contaminants

An important component of assessing potential risks to human health and the environment at contaminated sites and determining appropriate risk-management strategies is an evaluation of the fate of constituents of concern (COCs) as they migrate from the point of release to the potential receptor via an exposure pathway. At this Site, COCs include BETX and MTBE and each of these chemicals is subjected to various transport and degradation processes that influence the rate of migration, and that control the ultimate fate of the chemical in the subsurface. At this Site, the two impacted media include the water table aquifer, and site soils. The two principal

exposure pathways are via groundwater and soil vapor emissions. Based on Site data, the likely fate of the COCs in these two exposure pathways can be inferred.

4.1.1 Groundwater

Completion of the groundwater exposure pathway requires that the COCs migrate from the point of release to the receptor. At this Site, because groundwater is not likely to be used for domestic use now or in the foreseeable future, the ingestion exposure pathway is incomplete. Assuming, however, that the water in the affected shallow water table aquifer is used in the distant future, a completed pathway may only occur if the COCs are not subject to degradation processes that essentially halt the rate of COC migration, or cause a reversal in the movement of the plume, that is, the plume may either stabilize, or begin to decrease in size. As noted previously (Rice et al., 1995a), biodegradation of FHCs in the groundwater due to the presence of indigenous microorganisms, tends to limit the distance that most dissolved hydrocarbons migrate, if the primary source(s) have been removed. When the rate of degradation of FHCs begins to equal or exceed the rate of input of dissolved FHCs from secondary sources, the apparent FHC plume may stabilize, or begin to decrease in size.

Groundwater data collected at the Site since 1991 indicate that biodegradation of the FHCs is probably occurring. Eleven groundwater monitor wells have been sampled four times since 1991. One new well, MW-1 was sampled by Weston (Weston, 1992b), but this well has now been abandoned. General mineral analyses from samples collected in 1991 are available for wells NGE-5 and NGE-6. In well NGE-5, total BTEX was approximately 150 µg/L, while the nitrate level was ND. Reported iron concentration was 3.6 mg/L. In contrast, nitrate levels in well NGE-6 were 3.3 mg/L and the iron concentration was 0.29 mg/L, with BETX values of about 550 µg/L. The changes in the concentration of electron acceptors suggest that biodegradation of these compounds was occurring in the vicinity of well NGE-5 at least as early as 1991.

More recent groundwater monitoring data also support the hypothesis that passive biodegradation is occurring at various locations within the apparent BETX and TPH_g plumes. Well NGE-9 is located approximately 1,200 feet south of the release area at the NEX station. In 1991, TPH_g values were 1,000 µg/L. In October 1996, TPH_g in this well had decreased to less than 100 µg/L, or the detection limit. Monitor well NGE-8, which is located less than 500 feet south of the NEX station, has a similar history, with TPH_g levels at 2,600 µg/L in 1991, decreasing to below detection limits (100 µg/L) by October 1996. Dissolved oxygen levels in these wells were between 1.5 and 3 mg/L in 1996, suggesting that aerobic oxidation is now occurring. These data are consistent with the hypothesis that natural attenuation has occurred and is occurring at the eastern boundary of the BETX plume located east of North Richmond Road. In contrast to the apparent natural degradation of BETX compounds, MTBE results from these monitor wells suggest that MTBE is still migrating away from the source.

Evidence for biodegradation of the FHCs in the portion of the BETX plume located west of North Richmond Road is less robust. In well NGE-5, the concentration history for BETX between 1991, and the most recent sampling event (May 1997) shows that decreases in benzene, and toluene have occurred, but the concentrations of ethylbenzene and total xylenes have increased. This well would be expected to be directly impacted by FHC releases from the uncapped product piping. In monitor well NGE-11, BETX levels increased from 1991 to October 1996, but the May 1997 sample showed a slight decrease in both BETX and TPH_g.

The dissolved oxygen level in this well in October 1996 was 0.6 mg/L, indicative of anoxic conditions. Biodegradation is clearly occurring, probably via anaerobic pathways, but data are not sufficient to determine the rate of this process at this location. Additional evidence for anaerobic biodegradation processes include the soil gas measurements by Montgomery-Watson (1997). Samples from all six sampling locations within the 10,000 µg/L contour for TPH_g

(AGS, 1997), show methane levels generally higher than background levels. Unfortunately, there are no other wells that provide historical data for BETX downgradient or cross gradient from NGE-11. However, the recent sampling events have located the likely western boundary for the BETX plume, bounded at least by NGE-10, and SCAPS locations W08 and W06. The southern boundary of this plume also now appears to be near the location of HP-13 as confirmed by SCAPS sample location, W12. Since HP-13 exhibited a benzene level of 7.8 $\mu\text{g/L}$ in 1991, the ND reading from SCAPS W12 location suggests that the leading edge of this westerly BETX plume may have stabilized or is decreasing in size.

Thus, the data support an hypothesis of passive biodegradation of FHCs in the BETX plume. As noted previously, significant residual FHCs persist in the groundwater between NGE-4 and NGE-11, and possibly as far as well W11. However, because the primary source has been removed, and because both biodegradation and volatilization processes may be acting on the residual FHCs, the BETX plume caused by this secondary source may be stabilizing.

In contrast to the behavior of the BETX and TPH_g plumes which appear to be stable or decreasing in size in some areas of the BETX plume, the fate of the MTBE at the Site is uncertain. It appears that MTBE in the eastern portion of the FHC plume may still be migrating in the south easterly direction, and MTBE appears to have migrated past the BETX plume. The MTBE concentration at NGE-9 is 17 $\mu\text{g/L}$, which is below the Department of Health Services action level of 35 $\mu\text{g/L}$, but above the probable proposed secondary standard for MTBE of 5 $\mu\text{g/L}$ (Spath, 1997). In the western portion of the FHC plume, MTBE levels from monitor wells exhibiting the presence of residual FHCs (e.g., monitor wells NGE-5 and NGE-11) ranged from 250 to 1,100 $\mu\text{g/L}$. These levels decreased since the October 1996 sampling, and MTBE concentrations in NGE-10, a well apparently outside of the BETX plume is ND. Thus, MTBE levels in this portion of the FHC plume may be decreasing. MTBE also decreased in samples from NGE-3 (520 $\mu\text{g/L}$ to 27 $\mu\text{g/L}$) between sampling events. Thus, monitoring data does not indicate that MTBE has ceased migrating, and the potential for continued impacts to groundwater quality persists.

4.1.2. Soil Vapor

Given the known and inferred presence of residual product in the groundwater south of the Site, releases of BETX, MTBE and other volatile FHCs into the soil gas would be expected. However, the recent soil gas investigation (Montgomery Watson, 1997) found no evidence of BETX or MTBE in the soil gas, although methane levels from many of the samples were above background levels. All soil gas samples taken to a depth of 10 to 20 feet bgs were ND for BETX. It is possible that BETX vapors being released from the water table, which is approximately 30 feet bgs, are degraded before reaching the 10 foot bgs level. Alternatively, the quantities of residual FHCs may be sufficiently reduced such that the vapor flux to the surface from the residual FHCs may be too small to detect. A third hypothesis is that groundwater elevations have increased over the past few years, and the residual FHCs have become submerged, thus inhibiting the release of VOCs into the soil gas. This last hypothesis is supported by changes in groundwater elevation due to heavy rains over the past few years, and the apparent change in groundwater direction from southwesterly to southeasterly, a shift in the groundwater direction supported by the extent of FHC contamination west of the primary point of release. In any event, the recent soil gas investigation has shown that this exposure pathway is currently unlikely to cause the release of BETX compounds or MTBE at levels representing any significant health risks to onsite and offsite receptors. Should the groundwater elevations decrease in the future, it is possible that releases of VOCs to the soil gas could occur. The magnitude of such a release cannot be easily estimated.

Montgomery Watson (1997) used the soil gas data, and the concentrations of BETX compounds in the groundwater to conduct a screening level risk assessment. They concluded that under a no action alternative, risks to the reasonably maximum exposed individual were

below the one in a million threshold human health risk level. The non cancer hazard index was well below 1. Even using very conservative default assumptions, and the maximum observed benzene concentrations in groundwater, the risks to human health due to vapor inhalation were deemed below any regulatory significance.

The recent report by AGS has extended this screening level risk assessment to complete a draft baseline risk assessment for both human health and ecological risk assessments. The report summarizes the methodologies and assumptions used to complete the baseline risk assessment, and concludes that estimated risks to human health and the environment are below levels of regulatory concern. Cancer risks to human receptors were below 1×10^{-6} , which is considered to be a *de minimus* level with no restrictions on future land use. The noncarcinogenic hazard index and the ecological hazard quotient were both less than 1.0, indicating no significant risks from the site, under a no-further action scenario.

We have not completed a detailed critical review of this baseline risk assessment, but we do note that the methodologies and assumptions used are consistent with EPA guidance on conducting such analyses. Further, the assumptions were highly conservative, assuming for example, that the highest observed levels of BETX compounds in the extracted soil gas were representative of exposure concentrations, and assuming that the source term would experience no diminution over time. Thus, the baseline risk assessment probably overstates the actual risks to human health and the environment posed by this Site, assuming no active remediation of the soil or groundwater.

4.2. Remedial Goals

A second key issue that must be addressed to determine appropriate risk-management strategies for a contaminated site is establishing remedial or cleanup goals that must be met before the site may be considered closed. Cleanup requirements are set by states to ensure that sufficient contamination is removed to protect human health and the environment. Other factors that may be considered include, state-specific considerations such as potential use of the groundwater, groundwater yield, aquifer beneficial use designation, cleanup costs versus risks, technical feasibility of cleanup, available expertise, available funding, permitting, and future land use. Generally, guidance is available from the states or EPA which establishes the process for setting remedial goals. At National Priority List sites managed under the Superfund statutes, the process has been clearly established. For UST sites alternative approaches can be used by responsible parties, such as the use of a risk-based decision process.

The cleanup goals set by states usually fall into one of three broad categories: (1) technology based goals, which are based on the detection limits of analytical laboratory equipment (examples include the use of maximum contaminant levels under the Safe Drinking Water Act); (2) subjective goals, which are often adopted based on technology limits or in the absence of another mechanism; these standards may require cleanup to non-detectable or background levels; and (3) risk-based goals, which can be either an overall goal based on conservative yet realistic exposure and toxicity analysis, or site specific goals based on site specific conditions, land use, and exposure scenarios.

To establish a basis for site closure, the remedial goals must be satisfied either at all locations throughout the plume or at some boundary beyond which the plume cannot be allowed to migrate, for example, a property boundary. Remedial goals may also include some time frame within which the goals must be met. If conditions at the site do not exceed remedial goals, the site will usually receive a status of "no further action required at this time." If site conditions exceed remedial goals, then several options exist (Small, 1993):

Cleanup to background or non-detect: This approach is very protective of human health and the environment, but can often prove to be prohibitively expensive or technically infeasible.

Cleanup to an overall or generic goal: This approach is also protective, feasible in many cases, and generally less expensive than cleanup to background or non-detect levels. However, achieving these levels, which are often specified as maximum contaminant levels, may still prove to be prohibitively expensive, or even technically infeasible for some sites.

Cleanup to a site-specific goal: The protectiveness of this approach is usually based on specified land uses and may need to be re-evaluated if changes occur. The cleanup levels are often more feasible and generally less expensive to achieve. However, this approach requires site-specific exposure and risk assessment, to determine threats and impacts. The acceptability of such an assessment to some stakeholders at a site may be limited.

Risk management or containment: When contaminant concentrations exceed the remedial goals, but such goals cannot feasibly be achieved, then risk management through containment of contamination to prevent further migration may be an option. Active containment systems are often expensive to install and maintain, and require long term institutional control. Passive containment systems are less expensive but have uncertain durability for long-term containment. The continued presence of contamination in the subsurface may also decrease the value of the property.

No Action: In some instances no remedial actions, including monitoring may be needed because of no or *de minimus* future risks to human health and the environment. As with monitored natural attenuation, this approach may require site-specific exposure and risk assessment, to determine whether the site poses unacceptable threats to public health and the environment.

4.3. Remedial Technology or Process Selection

If contaminant concentrations exceed remedial goals and cleanup is required, then a cleanup technology must be selected based on the information obtained from site assessment and characterization. This technology should be selected based on the ability to meet remedial goals, site conditions, and physio-chemical properties of the contaminants. The technology should not create additional hazards (e.g., air sparging without soil vapor extraction that may potentially transport vapors into buildings).

The technology should ideally perform this task quickly, efficiently, and cost effectively. It is also important to give some consideration to how the cleanup technology or process actually accomplishes concentration reductions and where the removed contaminants or by products are actually going. There are four basic alternatives:

1. Reuse/recycling.
2. Waste destruction (or conversion).
3. Media transfer.
4. Waste disposal.

Media transfer and disposal options may simply move the contamination to another location where it will have to be cleaned up again. Whereas reuse, recycling, and destruction technologies or processes offer more long-term or permanent solutions.

Monitored natural attenuation or passive bioremediation may provide cost effective containment at some sites. In some instances where contamination exceeds remedial goals, but no immediate threats or impacts are identified, it may be acceptable to allow contamination to remain in place without active remediation. Monitored Natural dilution, attenuation, and degradation processes are allowed to slowly reduce concentration levels. However, this

approach may require site-specific exposure and risk assessment, to determine threats and impacts to public health and the environment (Small, 1993).

4.4. Remedial Action Alternatives for NEX Site

Remedial goals to reach closure have not yet been established for the groundwater at the NEX Site, which includes the contaminated aquifer zones both on the NEX property and downgradient from the Site. Options include: (1) cleanup to background, that is, complete removal of all FHCs, (2) cleanup to maximum contaminant levels for the COCs at the Site (BETX and MTBE), and (3) risk-based goals, with the option of applying these goals throughout the aquifer, or at the property boundary. Depending upon the agreed upon goal, several remedial options could be pursued at this Site.

Alternative 1: Cleanup to Background Throughout the Plume

From a resource protection perspective, this goal may often be preferred by regulatory agencies. However, achieving this goal to reach closure within a reasonable time frame is not likely to be feasible. Furthermore, based on the baseline risk assessment completed for the Site, there are minimal risks to human health and the environment, despite the presence of significant quantities of FHCs in both the dissolved phase, and as residual product in the water table aquifer beneath the Site. Thus, accepting this closure goal, and undertaking the necessary remedial actions would not be an appropriate use of financial resources. The costs far exceed the benefits because of the limited uses of the groundwater in the shallow aquifer.

Alternative 2: Cleanup to MCLs Throughout the Plume

This closure goal may be achievable with a combination of extraction technologies, engineered *in-situ* biodegradation, and monitored natural attenuation. The remedial action is likely to be costly, and may not achieve the remedial goal in a reasonable time frame. Strict interpretation of current California regulations for groundwater cleanups would require that this option be pursued, until it can be shown that further cleanup is not necessary for protection of human health or the environment and is not cost effective. However, from a risk perspective, such a remedial action is not warranted, because of the minimal risks to human health and the environment.

Alternative 3: Removal of FHCs from Subsurface to the Extent Practicable

Under this option, no specific remedial action goal would be selected, and the selected remedial action plan leading to closure would address only the removal of FHC mass to the extent feasible given available technologies. Although this Site does not appear to pose unacceptable risks to human health and the environment, the groundwater contains a large dissolved BETX plume, and there is evidence of significant amounts of residual product remaining in the water table aquifer. Furthermore, monitoring data do not show that the BETX or MTBE plumes are stable, although there is evidence of ongoing natural degradation. Thus, the FHCs released at the NEX Site continue to cause degradation of water quality due to the apparent continued migration of the COCs at the Site, particularly MTBE. Undertaking an active remediation program to halt plume migration, and to remove some of the residual product would decrease the time required for natural attenuation of the FHCs remaining after cessation of the active remediation program. An analysis of this option by NAWS is recommended.

Alternative 4: Risk-Based Remedial Goals with Monitored Natural Attenuation

Because the Site appears to pose minimal risks, presumably setting risk-based goals would lead to a remedial action plan that would rely on monitored natural attenuation to remove the FHCs from the subsurface. Although there is evidence of aerobic and anaerobic degradation of the BETX compounds at the Site, and it appears that the eastern boundary of the BETX plume is decreasing in size, data were not sufficient to determine the rate of these processes. Thus, the time required to achieve any risk-based goals could not be accurately estimated at this time. Furthermore, MTBE would continue to migrate, because this compound either does not easily degrade biologically, or if biodegradation occurs under aerobic conditions, it appears to be at a rate significantly slower than the rate of BETX degradation under aerobic conditions. Thus, there are risks that this remedial strategy would not protect water quality, and that a greater volume of groundwater may be impacted. An evaluation of this option by NAWS is also recommended.

4.5. Uncertainties

Closure of this Site without active remediation will be difficult because significant uncertainties persist in the characterization of the Site, despite extensive investigations conducted for NAWS by numerous consultants. These uncertainties must be addressed by NAWS before a monitored natural attenuation remedial plan can be credibly advocated. The following discussion provides the EC's opinions on the significance of these uncertainties as they impact the selection of a risk-management strategy for this Site.

Regulators have expressed the opinion that there are significant data gaps at this Site, including inadequate characterization of the hydrogeology, inadequate soil gas survey, inadequate definition of the extent of free or residual product, and inadequate definition of the extent of the dissolved plume. As noted in this Report, the EC feels that the Site has been thoroughly characterized to a reasonable extent, but that data are still unavailable that facilitate a comparison of alternative risk-management strategies. These data include the following:

- a. **Stability of BETX and MTBE plumes.** Data indicate that in some portions of the groundwater south of the Site, BETX and MTBE are still migrating and that the plumes are not stable. Further groundwater sampling is recommended to determine whether these plumes have stabilized.
- b. **Potential for migration of FHCs to the deeper aquifer.** The EC has not reviewed data on the geology of the Site to determine the integrity of the aquitard separating the shallow aquifer from the deeper aquifer. Based on discussions with base personnel, it appears that the aquitard is thick and the potential for vertical migration extremely low. This is a key issue if a monitored natural attenuation remedial alternative is selected and NAWS should provide the regulators with the necessary evidence to support this position.
- c. **Rate of natural attenuation.** Qualitative evidence (e.g., geochemical indicator parameters) of passive bioremediation of FHCs is available from site groundwater monitoring data. However, the observed BETX plume length at the NAWS site (greater than 1,000 feet) is not consistent with the LUFT historical case analysis results, ranking above the 99th percentile. This suggests that either the rate of passive bioremediation at the site is very slow or that other factors are contributing to the unanticipated long plume length. One factor may be the high flow velocity at the site; several hundred feet per year based on hydraulic conductivity values and the hydraulic gradient. Using analytical models of an idealized flow and transport regime, such high groundwater velocities may be shown to produce long FHC plumes (greater than 1,000 feet) even under typical passive bioremediation rates (0.1% to 1% day⁻¹). This seems a logical explanation, as

there are no apparent atypical site-specific conditions which would be expected to substantially reduce the passive bioremediation rate. Nevertheless, an additional round of groundwater sampling should be undertaken to assess plume stability. Such data may provide insight into whether changing concentrations in portions of the BTEX plume represent actual plume growth or simply reflect local shifts in the direction of hydraulic gradient. An additional round of sampling will also permit further assessment of the MTBE plume behavior. Because the rate of MTBE transformation is significantly less than that of other FHCs, if transformation occurs at all, the MTBE plume should exhibit a greater tendency for continued migration in comparison to BTEX. The high groundwater velocities at the NAWS site would be expected to exacerbate this phenomenon. As such, the need for an active engineered approach for remediation of the MTBE plume should be identified before further expansion of the plume occurs.

- d. **Rate of volatilization.** It is likely that FHCs at this Site are subjected to significant volatilization because of the warm desert climate, and the relatively shallow depth to groundwater. However, the soil gas data did not support this hypothesis, although it is conceivable that either significant volatilization has already occurred, or the residual product is submerged beneath the water table. This issue should also be evaluated in detail by NAWS to support a selection of monitored natural attenuation as the preferred risk-management strategy at the Site.

5. Summary and Recommendations

5.1. Sources

FHCs have impacted the groundwater at the NEX Gasoline Station on the NAWS, China Lake, California. The two primary sources of FHC releases, three former USTs, and an uncapped product pipeline have been removed. Secondary sources of FHCs are still present, primarily as residual product and represent a continuing threat to groundwater quality in areas west of North Richmond Road. The extent of these secondary sources may be bounded by the 10,000 $\mu\text{g/L}$ isocontour line for TPH_g as noted in recent reports prepared for NAWS. There is evidence of significant secondary source reduction due to volatilization and biodegradation of the BETX compounds in at least a portion of the contaminated groundwater. MTBE concentrations in several monitor wells exceeds the current DHS action level of 35 $\mu\text{g/L}$, and the amount of MTBE present in the existing secondary sources is unknown.

5.2. Pathways

Two major pathways of concern at this Site are the water table aquifer and soil vapor. The eastern boundary of BETX plume has been decreasing in size since at least June 1996, and probably earlier, but the MTBE plume appears to be still migrating, and appears to have moved past the apparent edge of the BETX plume in this eastern portion of the FHC plumes.

The BETX and MTBE plumes west of North Richmond Road may also be stabilizing, but insufficient data are available to confirm this fact. For example, the fate of MTBE cannot be predicted. Fuel hydrocarbons in a residual state (i.e., not as mobile product) are likely present at or below the water table, at least between wells NGE-5 and NGE-11 because the levels for BETX exceed the 1 percent effective water solubility of these constituents. The direction of the dissolved plume emanating from this secondary source area contradicts the prevailing knowledge on groundwater directions, but because the gradient is quite flat in this region, anomalous migration patterns are not surprising and are consistent with the existence of possible preferential pathways.

Soil gas test results demonstrate that the vapor pathway is incomplete due either to biodegradation of BETX vapors, depletion of the residual FHC pool such that insufficient FHCs are present to produce detectable fluxes of these compounds in the soil gas, or submergence of the residual product beneath the water table.

5.3. Receptors

Potential receptors exist in the vicinity of the Site, and hypothetical receptors, such as future onsite or offsite workers, can be considered as potential receptors of exposure via the soil gas pathway. However, the lack of complete exposure pathways demonstrates that no receptors are currently at risk from FHCs released from the NEX Station. The recently completed baseline human health and ecological risk assessment (AGS, 1997) provides further documentation of the low level of current and future risks associated with this Site, assuming that no active remediation is undertaken at the Site.

5.4. Risk-Management Strategies

The NEX Site represents a significant challenge for closure. Monitored natural attenuation is a likely risk-management strategy for portions of the BETX plume, provided that the MTBE plume can be shown to be stable. If the MTBE plume continues to migrate, further assessment of the ultimate impact on groundwater resources in the area must be considered. Although MTBE does not appear to pose significant risks to human health and the environment, MTBE can degrade water quality, and a larger volume of groundwater will likely be impacted.

Natural attenuation as the preferred risk-management strategy for the entire Site may not be acceptable because of the continued presence of residual FHCs, and the high values of MTBE observed. Although the recent baseline human health and ecological risk assessments indicate that current and future risks at the Site are below levels of regulatory concern, additional evaluation of active remediation strategies is needed due to the unknown long-term impact of the residual FHCs on water quality.

Such an evaluation is needed to support a risk-management strategy of natural attenuation. One suggested approach would be to install one or more additional monitor wells near the SCAPS location W11 and monitor the changes in BETX, MTBE, TPH_g, and geochemical indicators (dissolved oxygen, nitrate, sulfate, chloride, iron, and manganese) of biodegradation in these wells. It is likely that this portion of the plume has stabilized, and that natural attenuation will be a satisfactory risk-management strategy for this portion of the Site as well. However, it is necessary to estimate how long natural attenuation will take to restore the groundwater to acceptable cleanup levels. This may be difficult given uncertainties in the fate of MTBE.

5.5. Recommendations

The EC recommends that NAWS conduct the additional site characterization, and complete the additional analytical evaluations to determine if monitored natural attenuation is an acceptable risk-management strategy at this Site. Due to the presence of significant quantities of residual hydrocarbons, and the fact that the BETX and MTBE plumes do not appear to have stabilized, an active remediation program to halt plume migration, and to remove some of the residual product would decrease the time required for natural attenuation of the FHCs.

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Appendix A

Site Assessment Review to Apply Risk Based Corrective Action at Gas Exchange Site China Lake Naval Weapons Air Station China Lake, California



Lawrence Livermore National Laboratory

SITE ASSESSMENT REVIEW TO APPLY RISK BASED CORRECTIVE ACTION AT GAS EXCHANGE SITE CHINA LAKE NAVAL WEAPONS AIR STATION CHINA LAKE, CALIFORNIA

The Expert Committee (EC), established under the California Department of Defense Petroleum Hydrocarbon Cleanup Demonstration Program, has reviewed the methods and findings of the site investigations and remedial action plan prepared for the Naval Air Weapons Station (NAWS), China Lake, California to address contamination of the soil and ground water at the Naval Exchange Gas Station (NEX Site) located in China Lake, California. Enclosed is our assessment of the adequacy of the site characterization and site conceptual model as a basis for applying a risk-based corrective action methodology for selecting the appropriate risk management strategy at the Site.

This letter represents the first of two deliverable documents as part of our assessment. It is intended solely as a review of the existing Site data and risk characterization models. Recommendations regarding additional data needed to complete our assessment are provided.

SITE CONCEPTUAL MODEL

A well defined conceptual model of a site contains sufficient information to: a) identify sources of the contamination, b) determine the nature and extent of the contamination, c) identify the dominant fate and transport characteristics of the site, d) specify potential exposure pathways, and e) identify potential receptors that may be impacted by the contamination. For the NEX Site, several site investigations have been completed since 1990. (Weston, 1992a; Radian, 1996; Jaykim Engineers, 1989 & 1990). The results of the Jaykim investigations were not available for review by the EC.

Sources

The primary sources of soil and ground water contamination at the Site have been clearly established. A gas station has been in operation at the Site since 1967 and the Site contained four underground storage tanks (USTs) as well as necessary underground piping for product transfers. In 1993, during replacement of the original tanks and piping, an uncapped pipe was discovered extending past the third pump island on the Site. This pipe is considered to be the likely source of the majority of fuel hydrocarbons found in the soil and ground water. The distribution of fuel hydrocarbons in the soil and ground water beneath the Site is consistent with this release scenario. Releases of fuel hydrocarbons may have occurred from the original tanks as two of these tanks reportedly failed leakage tests in 1991. It appears that the tanks and piping are no longer leaking fuel hydrocarbons into the subsurface, although at least one monitoring well (NGE-3) reports an increase in benzene between 1991 and 1996 from non detect (ND) to 160 ug/L.

Ground water sampling events in 1990 to 1991 indicated the presence of floating product in well NGE-4. The presence of floating product would be anticipated based on the release scenario from an uncapped subsurface pipe. In the two subsequent ground water sampling events (June, 1996, and October, 1996), no floating product was reported in any of the ten wells sampled. Concentrations of benzene, ethyl benzene, toluene, and xylenes (BETX) and total petroleum hydrocarbons as gasoline (TPH_g) in one of the wells (NGE-11) approximated solubility limits for these compounds, however, suggesting that non-aqueous phase liquids (NAPLs) are present

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on the water table. The magnitude of this secondary source has not been reported, and the data currently available are not sufficient to estimate the quantity of NAPL present.

Nature and Extent of Contamination

The contaminants identified in the soil and ground water at the Site consist of volatile aromatic hydrocarbons, total petroleum hydrocarbons as gasoline, and methyl-tert butyl ether (MTBE), an additive blended with gasoline sold in California after approximately 1976. Currently, gasoline contains up to 11 percent (%) by volume, MTBE. No other chemical contaminants were reported. It is likely that other gasoline constituents are present in the soil and ground water, because the TPH_g measurement encompasses a limited range of alkanes present in the gasoline. However, the aromatic hydrocarbons and MTBE represent the constituents of fuel hydrocarbons posing the predominate potential risks to human health and the environment because of their relative mobility in the unsaturated and saturated zones beneath the site.

The extent of fuel hydrocarbon (FHC) contamination in the soils is well defined based on the soil boring investigation completed by Weston (Weston, 1992a). The extent of contamination in the ground water is also well defined. The upgradient and downgradient limits of the BETX and TPH_g plumes are reasonably well defined although the downgradient edge of the benzene plume, defined as the MCL concentration (1 ug/L) has not been specified. The location of the western edge of the BETX plume is also uncertain. For example, the benzene level in monitoring well NGE-9, the most downgradient monitoring well was 3.9 ug/L in the October, 1996 sample. Because the upper water table aquifer is relatively thin (5 to 28 feet), defining the vertical distribution of FHCs, particularly BETX, in the ground water is not essential for risk management decisions. Assuming that the results of ground water sampling represent a depth averaged concentration of the constituents of concern is an acceptable assumption for the purposes of site characterization.

Fate and Transport of Constituents

The site investigations to date have provided useful information on the hydrogeological parameters that would control the rate of migration of FHCs in the ground water. The direction of ground water flow towards the southeast has been confirmed by several ground water level monitoring events. The hydraulic gradient has been reported to range from 0.001 foot/foot (Radian, 1996) up to 0.04 ft/ft (Weston, 1992a). Weston suggests an average gradient of 0.009 ft/ft which seems reasonable based on a review of the ground water elevation data. Weston reports an average saturated porosity of 0.27, which is consistent with the stratigraphy of the saturated zone. Weston (Weston, 1992a) also reported the results of two pump tests using three of the monitoring wells in the immediate vicinity of the Site. The reported transmissivity values at these locations ranged from 0.13 to 6.1 ft²/min. The depth of the aquifer near these wells was approximately eight feet based on geologic cross sections prepared by Weston, and thus, the hydraulic conductivities ranged from 23.4 ft/day up to 1100 ft/day. Thus, average ground water velocities could range from 0.8 ft/day to 37 ft/day assuming the above average porosity. Given that the FHCs may have reached the ground water in the early 1970s, and that the plume length is approximately 1400 feet, the lower flow rates are more probable. Other useful hydrogeologic data available at the Site include the depth to ground water, the depth of the water bearing zone, and the permeability of the underlying clay layer separating the water table aquifer from the deeper aquifer zone.

Other key parameters influencing the fate and transport of the FHCs in the saturated zone include soil organic carbon fraction, and the geochemical conditions in the aquifer. No data were reported on soil organic carbon, but it can be inferred that the value would likely be low (less than 0.1%) given the nature of the geologic deposits in the desert environment of China Lake. Aquifer geochemical measurements are limited. Data available to the EC included general mineral results for three wells, NGE-5, NGE-6 from 1991 (Weston, 1992b), and NGE-5 and NGE-11 from 1996 (Radian, 1996). While these data are useful for assessing the possible biotic

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transformations of aromatic hydrocarbons, they are not sufficient to estimate the magnitude of such transformations.

The other significant mechanism influencing the fate of FHCs in the subsurface is volatilization. Floating product can volatilize and be transferred to the vapor phase at rates sufficient to remove substantial amounts of FHCs from the subsurface. This mechanism has not been addressed in any documents provided to the EC. However, given the desert climate, and the shallow depth to ground water, the EC expects that volatilization has resulted in removal of FHCs over time at the Site.

Exposure Pathways

The EC could find no discussion on the potential exposure pathways for migration of contaminants at the Site. Because no risk assessment has been completed at the Site, this issue was not addressed. Potential pathways include migration of FHC vapors through the vadose zone, migration of dissolved FHC constituents in the water table aquifer in the direction of the ground water flow, and migration of floating product (NAPLs) also in the direction of ground water flow. An additional pathway of concern is migration of FHCs into the deeper aquifer. Data presented indicate that this migration pathway is unlikely given the thickness of the clay layer beneath the water table aquifer and the low measured permeability values in this zone, combined with expected low values of FHCs near the bottom of the water table aquifer.

Potential Receptors

According to information prepared for the EC (Radian, 1996), there are no water supply wells within 1.5 miles of the NEX Site. The shallow ground water is not likely to be used as a drinking water source in the future because of high TDS (greater than 1200 mg/L). The water could potentially be used for non-potable uses, however. Thus, there are no risks to human health from ingestion of the water. If the water were used for irrigation, volatilization of the BETX compounds would occur, and human exposure is conceivable.

Migration of vapors from the subsurface could reach human receptors who live on the base in areas overlying or near the BETX plume. One area of concern is the nearby Murray School, located to the west of the BETX plume. Although the direction of ground water appears to be south southeast, away from the School, monitoring results in NGE-11 show the highest levels of BETX and TPH_G in the October, 1996 ground water sample. No explanation for these results has been provided. As noted above, these high values of BETX indicate the likely presence of free product in and around this monitoring well. Volatilization of these compounds in the subsurface and migration of the organic vapors to the ground surface is probable. The concentration of organic vapors at the ground surface will be difficult to estimate given the limited amount of ground water data in the vicinity of NGE-11.

SITE RISK CHARACTERIZATION AND MANAGEMENT STRATEGIES

At the direction of the NAWS, Weston (Weston, 1992b) prepared a remedial action plan for the Site, recommending active remediation using a pump and treat system. This proposal is currently on hold until an evaluation of the need for active remediation is verified. Based on data presented to the EC, no quantitative risks to human health or the environment have been evaluated for the Site. Although data gaps exist, as noted above, it is the opinion of the EC that sufficient information is either available or can be inferred based on professional judgment to complete a baseline risk assessment at the Site. Such an analysis is needed in order to determine if alternative remedial actions, such as natural attenuation, could be implemented at the Site. Based on research reported over the past few years regarding the natural degradation and attenuation of FHCs in the unsaturated zone and in ground water, it is possible that natural attenuation combined with continued ground water monitoring may be a viable remedial strategy at the Site.

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Some of the ground water data at the Site suggest that biodegradation of the FHCs is occurring. Weston (Weston, 1992b) reported general mineral analyses for two of the wells, NGE-5 and NGE-6. In well NGE-5, total BTEX was approximately 150 mg/L, and the nitrate level was ND. In contrast, nitrate levels in well NGE-6 were 3.3 mg/L, with BETX values of about 550 ug/L. These data suggest that oxidation of these compounds was occurring in the vicinity of well NGE-5. Also, in several of the wells, BETX levels have decreased between the 1991 and 1996 sampling events suggesting natural attenuation of the FHCs in the ground water. Monitoring well NGE-11 is the major exception to this observation, and the significant increase in BETX in this well indicates that at least some portions of the BETX plume are still migrating away from the original source area. Thus, the existing data are not sufficient to conduct a risk-based corrective action analysis. In RBCA terminology, this Site would be considered a Tier 3 site. The data do show, however, that natural attenuation is likely occurring, and that the human health and environmental risks at the Site for a natural attenuation remedial alternative may be sufficiently small to support a natural attenuation alternative. In addition, the apparent amount of hydrocarbons in the subsurface, based on the most recent data collected, is not consistent with the proposed release scenario. This suggests that natural attenuation, due to volatilization and/or biodegradation, is actively occurring. Thus, collection of additional site data, and preparation of a revised remedial action plan seem warranted.

ADDITIONAL DATA NEEDS

To date, only three rounds of ground water sampling have been completed. It also appears that general minerals have been measured in only three of the wells at two time intervals. The EC therefore recommends that an additional round of sampling be completed at all the active ground water monitoring wells. Samples should be analyzed for the same organic constituents previously measured (BETX, TPH_g and MTBE) and well as general minerals. Dissolved oxygen should also be measured in the field at all of the wells.

In addition, because of the significance of the high values of FHCs in monitoring well NGE-11, and the uncertainty regarding the source and mechanism of transport of FHCs to this area, the EC recommends that additional site characterization work be completed to define the extent of the dissolved BETX plume on the western side of the existing plume. Soil gas measurements in this area are also recommended to confirm the limits of residual or free phase product. The use of a geoprobe and hydropunch sampling is suggested to minimize costs.

In conjunction with these data, the EC recommends that the NAVY task one of their contractors to complete a detailed analysis of the natural attenuation alternative (biodegradation and volatilization) as well as completion of a baseline risk assessment for the Site. This alternative can be quantitatively evaluated if the new data set are used to estimate degradation rate constants for BETX compounds, based either on detailed data analyses or on best professional judgment using degradation rates reported in the literature for sites with similar hydrogeochemical and climatological conditions. Uncertainties in chemical and hydrogeological parameters can be addressed through the use of appropriate probability distribution functions for the controlling parameters. The EC can provide suggestions to the Navy based on similar analyses completed at other sites evaluated by the EC (e.g., George Air Force Base). The baseline risk assessment should be completed using protocols acceptable to the RWQCB.

SUMMARY

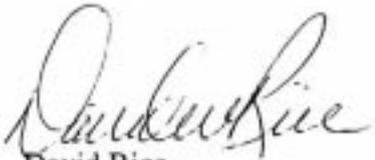
The NEX Site presents a number of challenges. Sufficient data have been collected to define the sources of contamination, the nature of the contamination, the probable extent of the major constituents of concern, the direction and rate of ground water flow, and the potential pathways and receptors at the Site. However, significant data anomalies persist. These include: 1) the source of the increasing BETX and TPH_g contamination in NGE-11, a location which is cross gradient to the primary source, 2) the quantity of residual or free floating product in the subsurface, 3) the rate of ground water flow, and BETX migration given the significant variations in key hydrogeologic parameters presented in consultant reports (e.g., hydraulic

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gradients, hydraulic conductivities), 4) the interpretation of the general mineral results and the significant differences in TDS values between wells within a few hundred feet of each other, 5) the actual length of the plume, and 6) the extent of BETX plume beneath the Murray School athletic field. The increase in contamination in monitoring well NGE-11 is particularly troubling. A review of the utility map provided to the EC does not indicate the presence of a sewer line, or other utility corridor that could account for the anomalous contamination. A review of the ground water characterization study at the Murray School (Smith-Gutcher, 1995) did not reveal another potential source for this contamination.

Following receipt of the additional site data, and the recommended evaluations, we will prepare the final deliverable containing our recommendations on the application of a RBCA-like process to the Site for selection of remedial actions and recommended procedures to achieve closure of the Site.

Sincerely,



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